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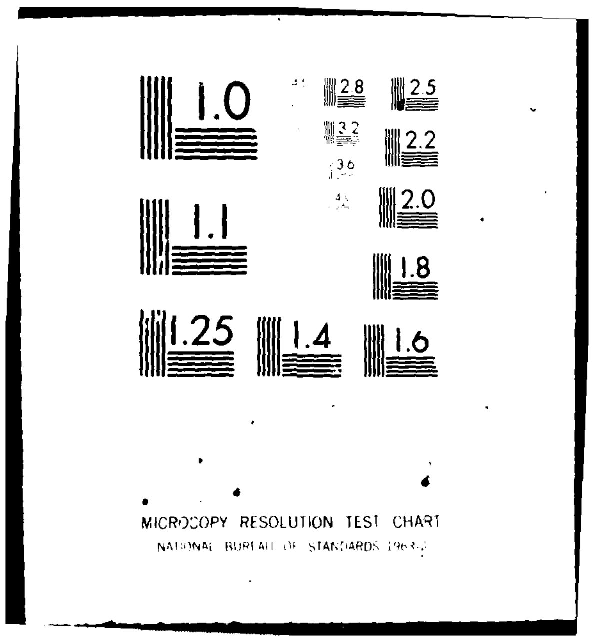
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EFFECTS OF PIPE WALL MASS DISTRIBUTION IN LINE-OF-SIGHT NUCLEAR TESTS

Systems, Science and Software, Inc.
P.O. Box 1620
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1 August 1978

Topical Report for Period September 1977—July 1978

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The results of a continuing investigation into the possibility that the introduction of asymmetries into the horizontal line-of-sight pipe on a nuclear event may be able to reduce the flow of energetic materials down this pipe is presented here. In an attempt to model the three-dimensional asymmetric configurations, two-dimensional planar calculations were made in which the spiral wrap was approximated by alternating pieces of iron along the top and bottom of the pipe (channel). For the cases studied, it appears that increasing

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20. ABSTRACT (Continued)

the amount of iron around the pipe reduces the energy of the jet and that this iron should be placed symmetrically about the pipe. However, the results indicated some deflection of the jet off axis in the spiral approximated.

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1. INTRODUCTION SUMMARY AND CONCLUSIONS

The work reported here is part of a continuing effort to understand the processes which generate energetic gases and high velocity condensed matter in the line-of-sight (LOS) pipe. These materials constitute major threats to experimental objects in nuclear testing. Expensive sample protection hardware is employed to protect the experiments from these threats. The objective of the long term study is to minimize the generation of energetic threats by optimal choices of materials and configurations in the vicinity of the source. This can potentially result in large reductions in the cost of sample protection without any reduction in the margin of safety.

The initial phase of an investigation into the possibility that the introduction of asymmetries into the LOS may be able to reduce the above threats was reported[1] in July 1975. It had been recognized for several years, on the basis of 2-D calculations in axisymmetric geometry, that a jet of condensed material (mostly grout) is generated by the shock-driven collapse of the LOS. The energetic gases in the LOS derive most of their energy from the same process. It was conjectured that asymmetries, e.g., a heavy iron spiral wrapped around the much thinner LOS pipe, could result in a large reduction in the energy of the jetted grout as well as a significant deflection of the jet off-axis. It was felt that some reduction in the energy of the gas flow might also result.

The difficulty in analyzing asymmetries is that they make the geometry three-dimensional. To make the problem tractable, we treated the asymmetry in two-dimensional plane geometry, in a plane containing the LOS axis. An iron spiral, for example, is represented in this geometry as a series of iron slabs on alternating sides of the channel which represents the pipe (see Figure 1). In the earlier study,[1] five calculations

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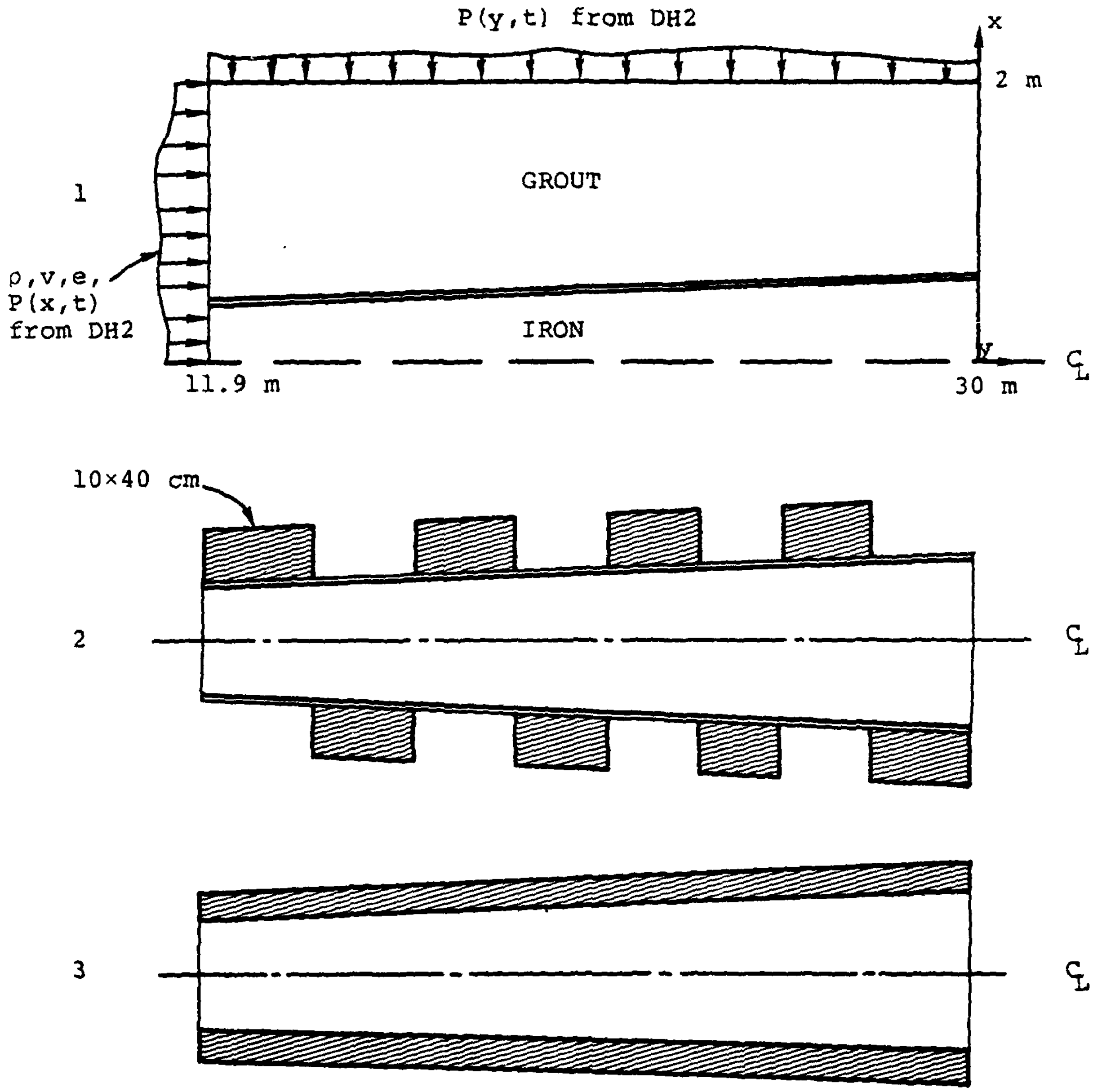

Figure 1. Schematic of calculational grid and boundary conditions. Top and right boundaries are transmissive.

were carried out: a symmetric, standard configuration which was a plane-geometry analog of a previously performed calculation for the Husky Ace event, and four different variants of this configuration obtained by using various arrays of 10 cm thick iron slabs. All calculations were driven in the same manner by the imposition of velocity, density, and specific energy as functions of time at the left of the grid shown in Figure 1.

The asymmetric configurations calculated included: a 10 cm iron slab on one complete side of the channel; a representation of a spiral using 10 cm thick iron slabs 100 cm in length on alternating sides of the channel; and a representation of a tighter spiral using slab segments 40cm in length. The final calculation was a symmetric case with continuous 10 cm slabs of iron along both sides of the channel (approximately twice the total amount of iron). This calculation was performed because the results of the three asymmetric cases were not very different from each other, although the channel flow in these three cases was significantly less energetic than for the standard plane geometry configuration. It was suspected that at the range from the source that was being studied, the important parameter was the amount of iron used rather than its partitioning between the two sides of the channel. The larger iron results showed that this was indeed the case; the channel flow and grout jetting in this calculation were considerably less energetic than in the asymmetric calculations.

The use of solid iron slabs seemed to cause roughly comparable reduction of the energy of gas flow in the channel and of the jet of condensed grout. Only a slight deflection of the jet off-axis in any of the asymmetric configurations was noted; the deflection was insufficient to prevent it from impacting fast closure hardware in typical configurations.

The findings of this study were consistent with those of a concurrent parameter study of the effects of material and

configuration changes close to the source on energetic vapor flow and jetting in the LOS. The major finding of that study was that large increases in the density and the length of the reverse cone extension each result in large reductions in the energy in both the LOS gas flow and the grout jet. This finding has been explained in terms of inertial effects. The high density material results in slower pipe expansion in response to the initial gas flow, lower maximum radii at each distance from the source and consequently, less PdV work performed on the vapor ahead of the advancing ground-shock-driven collapse. The same interpretation was applied to the results of the first asymmetry study.

The above mentioned parameter study has important implications for the continuation of the study of asymmetries. The configurations considered in that study resulted in much greater reductions of calculated energy flow in the LOS than did any asymmetries considered in our earlier study. A long, heavy tuballoy extension was in fact used successfully in the Mighty Epic event to reduce the energy flow in the LOS pipe. Based on calculations to further optimize this configuration, a slightly different tuballoy extension will be used in the Diablo Hawk test. Therefore, the continuation of the asymmetry study presented here considers asymmetries in the context of an LOS pipe with a tuballoy extension. This configuration has an order of magnitude less energy flowing down the pipe than the Husky Ace configuration.

The three configurations for the calculations which were used in this continuing study are shown schematically in Figure 1. The first, or standard baseline calculation, consisted of a symmetric slab geometry simulation of the cylindrically symmetric Diablo Hawk (DH2) UNION calculation. This calculation was begun at a time of 0.6 msec, just before the ground shock reached the end of the tuballoy extension located 11.9 meters from the source, and was terminated at 4.0 msec. For this

study, a tapered pipe was used rather than a straight pipe. Also, a far greater number of mesh zones were used to describe the LOS pipe region. In other respects, the calculational technique was similar to the earlier study and is described in Section 2, where results obtained with the standard configuration are also compared with the Diablo Hawk (DH2) results.

In the second configuration, the spiral asymmetry was represented by 10 cm thick iron segments 40 cm in length on alternating sides of the channel. The effect of the spiral wrap was to lower the total integrated energy (TIE) ahead of ground shock by 50 percent as compared to the standard symmetric geometry. The jet in the spiral case was found to propagate more slowly and to be deflected off-axis. The jet was calculated to contain a significant quantity of melted grout only on one side of the pipe (channel).

In the third calculation, a mass of iron equal to that used in the spiral case was placed symmetrically around the pipe. In slab geometry this corresponds to a 5 cm thick layer of iron along the upper and lower surfaces of the LOS pipe. The resulting TIE ahead of ground shock was found to be approximately 30 percent lower than that obtained for the spiral wrap case. The jetted material did not contain any grout.

These three calculations reinforce the conclusions of the earlier study, i.e., that the amount of energy flowing down the pipe is primarily a function of the amount of mass (iron or tuballoy) around the pipe and that the best configuration is the one which reduces pipe expansion the most. For the reduced energy flows corresponding to the Diablo Hawk event, the effects of adding iron around the pipe were greater than for the greater energy flows corresponding to the Husky Ace configuration. In the limit of no pipe flow other than that generated by the ground shock driven pipe collapse, any additional mass added around the pipe could be significant in changing the character of the jetted material.

Recent experiments performed at Physics International[2] have demonstrated that for explosively collapsed pipes, spiral asymmetries appear to significantly reduce the jetting down the pipe. In the "no pipe flow" limit, the jetted materials penetrated completely through a 4 inch thick aluminum target plate, at the end of the 2 inch diameter pipe. When a helical lead ribbon (spiral asymmetry) was placed around the pipe, the target plate suffered only negligible damage. No conclusive explanation has been given as yet for the qualitative difference between the results of the PI experiments and the calculations presented here. The slab geometry used in these calculations ignores cylindrical convergence which may be a key feature in evaluating the influence of a spiral asymmetry on the formation of energetic jets. A three-dimensional calculation may be required to resolve this question.

The present study could also be extended in order to investigate the affect of asymmetry in the "no pipe flow" limit. Calculations 1 and 2 (the symmetric and asymmetric pipes) can easily be redone assuming that iron gas is not initially present in the pipe and that no plasma is allowed to enter the pipe region through the grid boundaries. Since the remaining boundary conditions would be the same as in the present study, we would expect the same ground shock in the grout surrounding the pipe. Thus, these calculations would also give a good comparison between the effects of pipe asymmetries with and without pipe flow.

2. DESCRIPTION OF THE MODELING

The three configurations indicated schematically in Figure 1 were studied with the Eulerian hydrodynamic code DORF9. DORF9 is in the RADOIL family of codes and includes material strength. The line-of-sight is along the y-axis and the pipe (channel) is assumed to have unit depth in the z-direction. The calculational grid was chosen to extend from the end of the tub-alloy extension (11.9 meters axially from the source) out to approximately 30 meters from the source and to extend radially 2 meters from the LOS axis in the $\pm$ x-direction. Pipe taper was included in the calculations. In order to describe the pipe material in great detail, 13,700 zones were used for the symmetric calculations and 27,400 for the asymmetric case. Minimum zone sizes in this grid were 5 cm axially and 1 cm radially in the pipe. Maximum zone sizes were 10 cm axially over the last 9 meters of pipe and 10 cm radially in the grout farthest away from the pipe. The AFWL CYPER 176 computer was used for all calculations.

Initial and boundary conditions for the calculation were modeled using the results of a cylindrical UNION calculation for the Diablo Hawk event (DH2). The grid was initialized at a time of 0.6 msec when the ground shock had just reached the end of the tuballoy extension. At this time, the pipe contains low density iron and tuballoy vapor ahead of the extension. The version of the DORF9 code used in the earlier study(1) is not equipped to handle three materials in any one cell. To avoid mixing problems, we decided to convert the vaporized tuballoy into iron.

The boundary conditions are shown schematically in Figure 1. The right of the grid was modeled as a transmissive boundary and the mass and energy flowing out were edited. Mass and energy were also allowed to flow out the top of the grid (and the bottom for asymmetric calculations). However, a pressure distribution, a function of axial position and time,

approximating the DH2 cylindrical results, was also applied at the top (and bottom) in order to minimize any rarefaction waves due to the boundary. It was also hoped that this pressure distribution could approximate to some extent the spherically divergent free field conditions.

Both grout and iron were allowed to flow into the grid through the left boundary (tuballoy was replaced by iron at the same energy and at a density which gave the same pressure). From the DH2 results, the location of an interface between grout and iron (tuballoy) at this boundary was chosen as a function of time. Distributions of density (ρ), axial velocity (V_y), and specific internal energy (e) were chosen as functions of X and time for the iron and grout. Mass and energy fluxes, computed from these distirbutions, were imposed along the left boundary. Pressure boundary aconditions were specified to be consistent with the densities and energies chosen.

The above initial and boundary conditions were chosen to give as close a correspondence as possible between the cylindrical DH2 calculation and these planar calculations. To check the agreement and to give a base with which to compare the asymmetric results, a symmetric plane calculation was made. Comparisons were made at times of 1.5 and 3.0 msec. At 3.0 msec, the pipe closure in both calculations is located 8.9 meters axially from the end of the extension. However, the grout shock wave is clearly weaker in the cylindrical DH2 calculation due to the diverging geometry.

Table 1 shows two comparisons between the slab and cylindrical results at mesh points corresponding to the grout shock wave location at a time of 1.5 msec. These comparisons show the excellent agreement between the calculations in all variables except V_x. This component of velocity represents the cylindrical convergence and divergence which cannot be adequately modeled in slab geometry.

Table 1. Comparisons between cylindrical and planar calculations at the ground shock location at t = 1.5 msec.

	X = 55 cm		X = 100 cm	
	Cylinder	Slab	Cylinder	Slab
y(cm)	260	260	260	270
p(mbars)	0.093	0.108	0.105	0.112
ρ(gms/cm^3)	2.78	2.94	2.78	2.95
e(ergs/gm)	8.44×10^9	8.23×10^9	9.15×10^9	8.69×10^9
V_x(cm/sec)	3.42×10^3	-2.1×10^4	1.14×10^4	-3.8×10^3
V_y(cm/sec)	1.35×10^5	1.36×10^5	1.43×10^5	1.41×10^5

3. DETAILED RESULTS

All three calculations were carried out to 4.0 msec at which time the shock-driven LOS pipe closure had propagated more than 10 meters axially from the extension. At this time, jetted material of significant density had reached the end of the calculational grid (approximately 18 meters from the extension). The most instructive comparison between the various calculations is of their total integrated energy (TIE). TIE, which is a function of axial distance y from the end of the extension, is the total energy in the problem at axial distances greater than y. Figure 2 shows the TIE curves for the three configurations at a time of 4.0 msec (these curves have been normalized to allow the presentation of both symmetric and asymmetric results on the same scale). At this time the ground shock in the vicinity of the LOS pipe is located approximately 11 meters from the end of the extension.

When compared with calculation 1, a 50 percent reduction in TIE ahead of ground shock was achieved by placing the iron asymmetrically about the pipe as in calculation 2. However, the best of the three calculations was calculation 3, in which the mass of iron placed asymmetrically in calculation 2 was used symmetrically around the pipe (channel). Calculation 3 gave approximately a 30 percent reduction in TIE ahead of ground shock when compared with calculation 2.

Figures 3, 4, and 5 are computer plots of the distribution of material and the density of the iron and grout in the grid for calculations 1, 2, and 3, respectively at a time of 4.0 msec. The LOS axis is vertical in all plots. For the symmetric cases (Figures 3 and 5) only one half the pipe is shown (the far left of the plot represents the axis of symmetry), while for the asymmetric case (Figure 4), the entire pipe cross-section is shown (the axis is drawn slightly to the right of center since the right portion of the grout is not plotted).

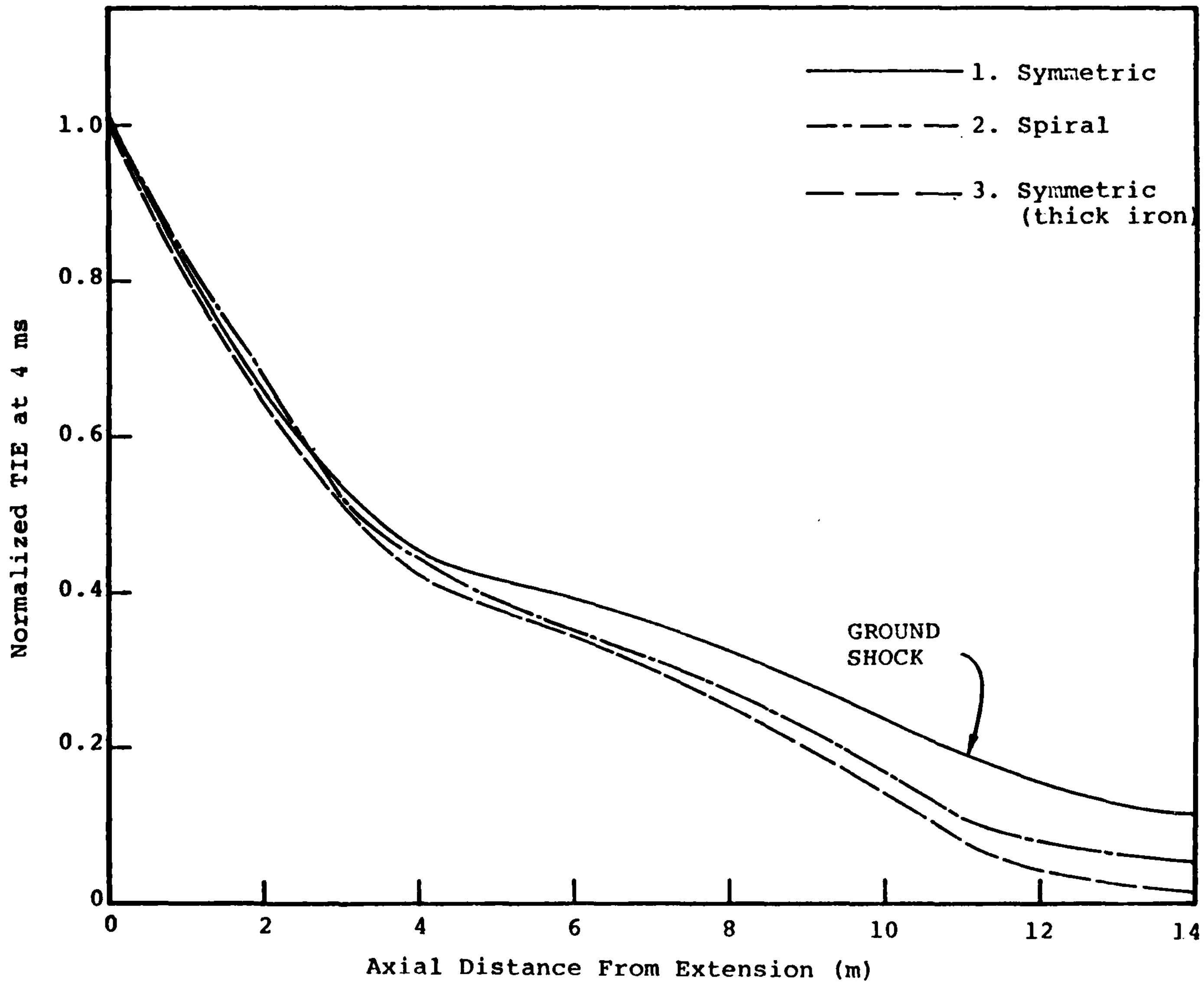

Figure 2. Total integrated energy (normalized to 1.0) vs axial distance from the extension (11.9 meters from the working point) at a time of 4.0 msec.

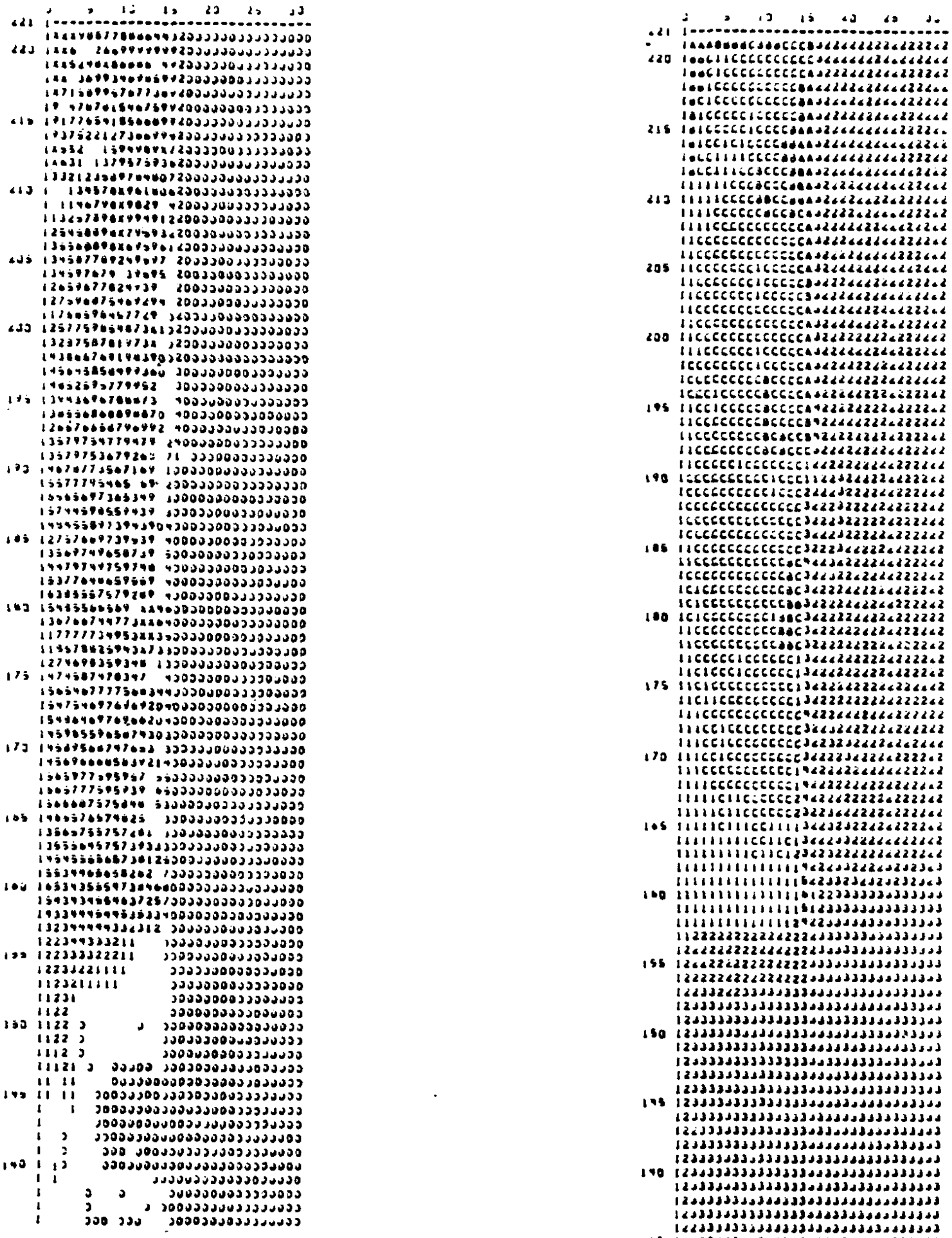

Figure 3. (a) Volume fraction of iron (X material) at 4.0 msec for calculation 1, the standard symmetric case. Blank represents less than 10 percent iron in a zone, 1 presents 10 to 20 percent iron, etc. X = 100 percent iron, while D represents 100 percent grout. Axis of pipe is vertical and on far left of computer plot.

(b) Density distribution in the grid. BLANK = < 0.01, A = 0.01-0.1, B = 0.1-0.2, C = 0.2-0.5, 1 = 0.5-1.0, 2 = 1-2 3 = 2-3, 4 = 3-4.

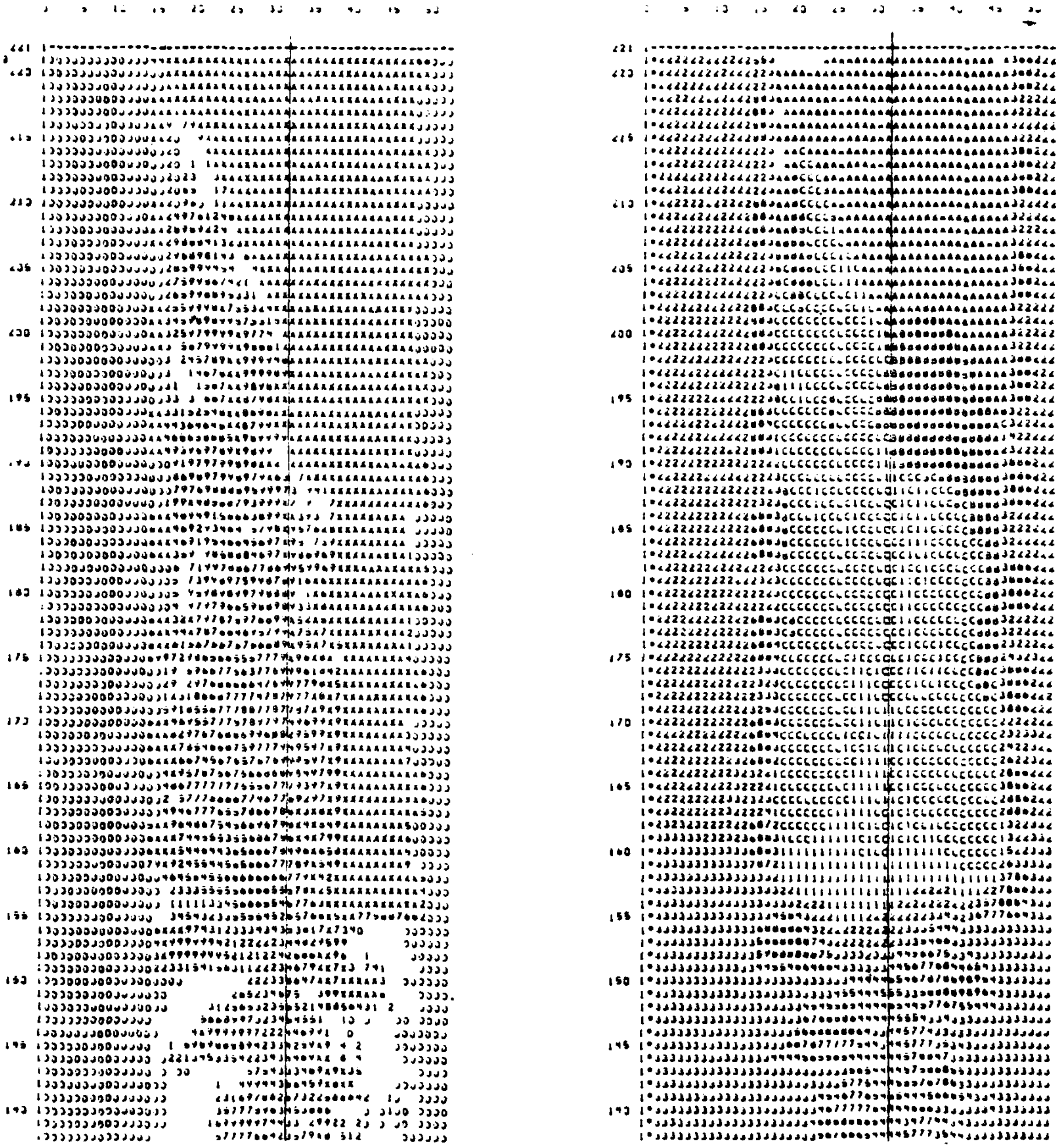

Figure 4. (a) Volume fraction of iron (X material) at 4.0 msec for calculation 2, the spiral asymmetry. Blank represents less than 10 percent iron in a zone, 1 represents 10 to 20 percent iron, etc. X = 100 percent iron, while D represents 100 percent grout. Axis of pipe is vertical as shown.

(b) Density distribution in the grid. BLANK = < 0.01, A = 0.01-0.1, B = 0.1-0.2, C = 0.2-0.5, 1 = 0.5-1.0, 2 = 1-2, 3 = 2-3, 4 = 3-4, 5 = 4-5, 6 = 5-6, 7 = 6-7, 8 = 7-8, 9 = 8-9.

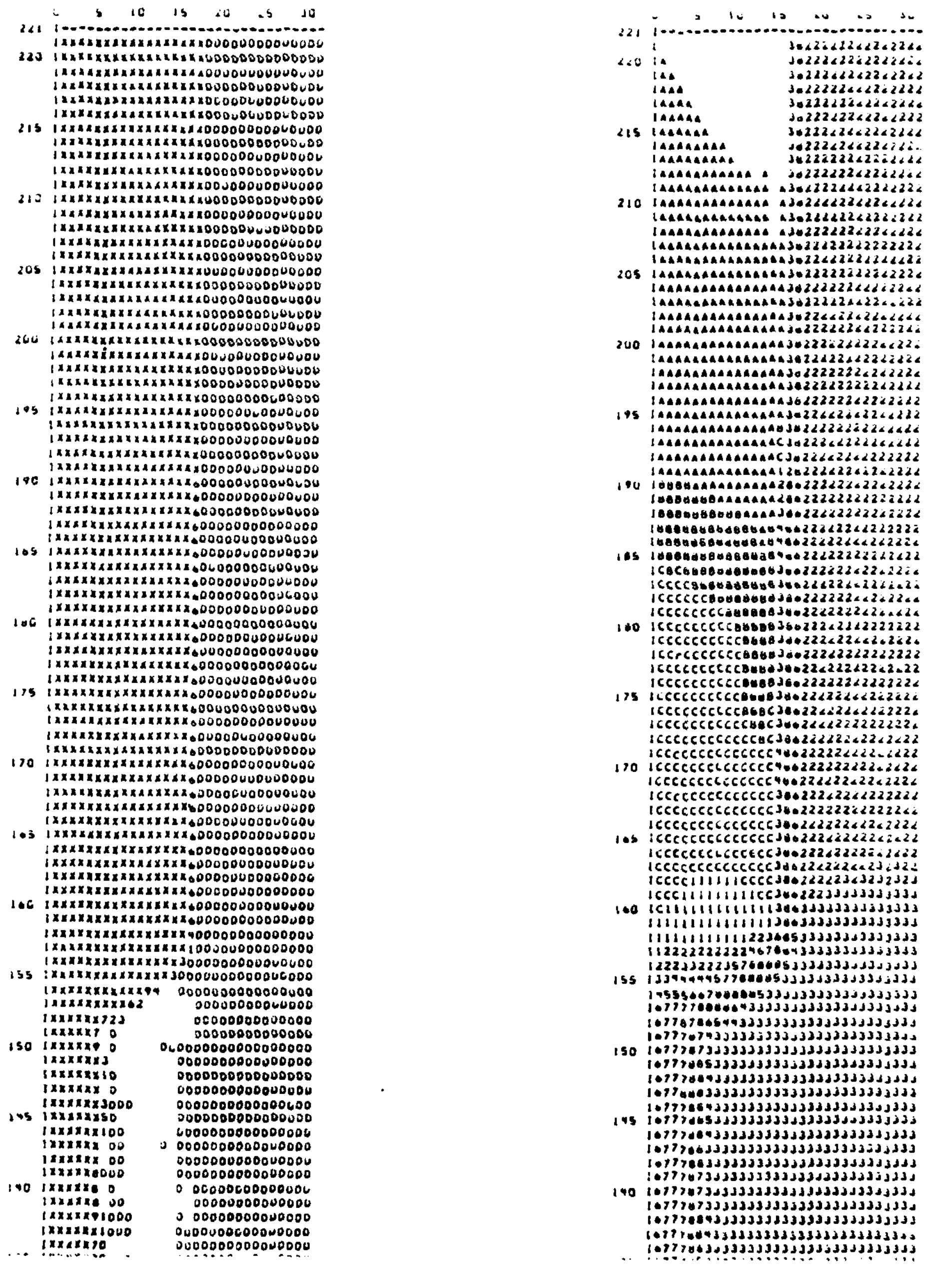

Figure 5. (a) Volume fraction of iron (X material) at 4.0 msec for calculation 3, the symmetric (thick iron) pipe. Blank represents less than 10 percent iron in a zone, 1 represents 10 to 20 percent iron, etc., X = 100 percent iron, while D represents 100 grout. Axis of pipe is vertical and on far left of computer plot.

(b) Density distribution in the grid. BLANK = 0.01, A = 0.01-0.1, B = 0.1-0.2, C = 0.2-0.5, 1 = 0.5-1.0, 2 = 1-2, 3 = 2-3, 4 = 3-4, 5 = 4-5, 6 = 5-6, 7 = 6-7, 8 = 7-8, 9 = 8-9

All plots give the grid zone numbers. Since zone size changes drastically along a cross-section, the pipe (the x material) appears much larger relative to the grout in these plots than its true size. In the vertical (axial) direction, all zones shown are 10 cm long (the part of the grid not plotted is upstream from the closure and does contain smaller zones).

Figures 3 through 5 give a fairly complete picture of the density distribution in the pipe region (radial zones 1 to 15). The ground shock extends axially up to approximately zone 159 or 160 as evidenced by the higher grout densities ($\rho > 2.0$) in Figure 3b, 4b, and 5b. Pipe closure can be located in Figure 3b at about zone 153 to 157 by the higher densities in the pipe region and in Figure 3a by the increasingly lower percentages of iron in this pipe region. In Figure 5 for the symmetric thick iron case, closure can be identified at roughly the same position by large densities corresponding to the additional solid iron (ρ_o = 7.87 gms/cc) around the pipe. For the asymmetric pipe (Figure 4), the pipe closure is different on either side of the centerline and ends 10 cm closer to the working point.

The jetted materials are distributed quite differently for the three calculations. For the standard symmetric configuration, Figure 3b shows material of density C (0.2-0.5 gms/cc) extending out to the very top of the grid. Figure 3a indicates that most of the jetted material is iron (mixed material cells with large integers indicate mostly iron) but that there is a concentration along the axis of symmetry (the left of the grid) of cells containing mostly grout. Note that Figure 3a shows the volume fraction of iron rather than the mass fraction. A two material (mixed) cell has both components at the same pressure, i.e., they have roughly the same ρe. Therefore, the volume fraction is roughly proportional to the energy fraction in the cell.

For the symmetric thick iron configuration shown in Figure 5, the jetted materials have much lower densities than for the standard case. Material of density C extends only to zone 184, i.e., approximately 3.8 meters further from the top of the grid than for the standard case. Most of the material in the jet is of density of 0.1 gms/cc or less. Material at the top of the grid has density less than 0.01 gms/cc. No grout can be seen in the jet in Figure 5a. This is primarily due to the iron blocking the path grout would take in jet formation.

Clearly, the addition of iron around the pipe has greatly reduced the mass of material being jetted. An explanation similar to that used in a previous report also appears to be valid here. It was shown there that after an initial injection of energetic vapor into the LOS from the vicinity of the zero room, the LOS begins to be occluded by the ground shock-driven collapse of grout into the axis. Most of the energy which eventually resides ahead of the occlusion derives from this collapse process. Energy is driven into the vapor ahead of occlusion by PdV work associated with the collapse and energy is also carried by the jetting of grout and iron which accompanies collapse. The use of denser material around the LOS (in this case the thick iron) reduces the pipe expansion which accompanies the initial injection and precedes collapse at any given station. Reduction of this expansion causes a reduction of both the PdV work during collapse and the jetting of iron and grout.

The use of a heavy tuballoy extension in the Mighty Epic event significantly reduced the pressure measured in front of the WP side of DAC #2 compared to any previous event. Also, the evidence suggests no increase in impact and erosion damage over that seen on Husky Ace even though the Mighty Epic door was 12% closer to the WP on a scaled basis. No other comparison is available with a door that survived, and in those cases of complete failure the cause of failure is unknown. This improvement in closure performance is probably indicated by the calculations reported earlier, but the qualitative magnitude of pressure and damage reduction is not as great as expected from the calculations alone.

The results for calculation 2, the model of the spiral asymmetry, shown in Figure 4, lie between those of calculations 1 and 3. Lower density material occurs near the top of the grid than for the standard case, but this material is at considerably higher density than the material for thick iron case. These calculations predict that the extra iron placed symmetrically about the pipe will do a better job in reducing the energy and density of jetted materials. However, the asymmetry could still be important if it could be shown to deflect the energetic jet so that certain expensive fast-closure hardware might be eliminated. Figure 4 clearly shows an asymmetric jet. The pipe contains only iron to the right of the centerline over a large axial distance. This iron has density A or B (0.01-0.2). To the left of the centerline, the jet contains a significant amount of grout and is of considerable higher density. From similar plots at earlier times, it appears that the grout has been deflected off axis very early in the calculation and that it has remained in that position as it propagated down the pipe. The extrapolation of this result to cylindrical geometry is not obvious. Clearly, these calculations lack the convergence and divergence properties of a cylindrical grid. Would the jet deflect enough to significantly alter the threat to the DAC door? It would seem to be very difficult to answer this question without a three-dimensional calculation. Such an investigation may be worthwhile.

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